Heliyon 5 (2019) e02467

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.heliyon.com

Low intensity light treatment improves purple kale (*Brassica oleracea* var. sabellica) postharvest preservation at room temperature

Alejandra Bárcena [a,b], Gustavo Martínez [a,b], Lorenza Costa [a,b,*]

[a] *Instituto de Fisiología Vegetal (INFIVE), Concejo Nacional de Investigaciones Científicas y Técnicas (CONICET) - Universidad Nacional de La Plata, Diagonal 113 N° 495, La Plata, 1900, Argentina*

[b] *Facultad de Ciencias Agrarias y Forestales de la Universidad Nacional de La Plata (FCAyF-UNLP), Calle 60 y 118, La Plata, 1900, Argentina*

ARTICLE INFO

Keywords:
Food science
Postharvest food processing
Agricultural science
Plant biology
Purple kale
Postharvest senescence
Anthocyanin
Antioxidant capacity
Light treatments

ABSTRACT

Purple Kale is a vegetable of the Brassicaceae family whose are popularly consumed in recent years due to their high level of healthy components. For consumption, matures leaves are harvested and postharvest senescence is induced. Changes in color leaves due to chlorophyll degradation are the main visible symptoms of postharvest senescence, but there are other changes that affect the nutritional quality of kale. The aim of this study was to investigate if low intensity light pulses could be used to delay postharvest senescence of purple kale stored at room temperature. Daily treatments with 1 h pulses of white or red light were performed. Irradiated samples had approximately 40% higher chlorophyll and protein and more of 20% higher antioxidant capacity and soluble sugar content than control samples regardless of light quality used in treatment (white or red). Both light treatments improve the appearance and quality of kale during storage at room temperature.

1. Introduction

Purple Kale (*Brassica oleracea* var. *sabellica*) is a leafy vegetable of the Brassicaceae family whose consumption has increased in the last years. Kale is mainly cultivated in Central and Northern Europe and North America as winter crops (Neugart et al., 2012), but it can be also grown all year in the tropical regions due to its tolerance to summer heat (Noichinda et al., 2007). Actually its production is extending to the Republic of Mexico, Chile and Argentina. Brassicaceae, are popularly consumed due to their high content of health promoting phytochemicals, such as glucosinolates, vitamin C and polyphenols (Björkman et al., 2011; Deng et al., 2017). Kale plants have a large number of phenolics compounds and the level and type of phenolic components are strongly influenced by growth conditions, i.e. temperature and irradiation (Neugart et al., 2013). There are different commercial cultivars of kale with different leaf color and shape. Additionally, purple kale has high content of carotenoids and anthocyanin which improves even more its quality (Walsh et al., 2015). Particularly, anthocyanin-rich food products have become increasingly popular due to their attractive colors and suggested benefits for human health (Pojer et al., 2013). Flavonoids, including anthocyanins, may scavenge reactive oxygen species (ROS) generated by metabolic process (Neill and Gould, 2003). Phenolic components in kale leaves depends strongly of temperature and Kale plant consists of many leaves which are inserted in a single stem that grows upwards. The harvest of mature leaves for consumption causes a severe stress that quickly triggers senescence. By this reason, kale becomes a perishable vegetable which deteriorates rapidly during postharvest storage. During senescence, changes in color leaves are the main visible symptoms of deterioration (Wang, 1998), but loss of proteins and sugar are also a common feature. Albornoz and Cantwell (2016) used overall visual quality, yellowing, discoloration/browning, and chlorophyll/carotenoids levels to analyzed kale marketability. Until the present, only few works about postharvest physiology or technology of kale have been published and, among them, generally Chinese kale (*Brassica oleracea* var. *alboglabra*) was the crop studied (Noichinda et al., 2007; Sun et al., 2012; Deng et al., 2017).

After harvest, the kale mature leaves turn yellow within a few days, if held at 20 °C or above (Noichinda et al., 2007). In general the loss of visual and nutritional quality of kale leaves increased with increasing of temperature and days of storage; therefore postharvest storage recommendations for this crop are refrigeration (0–5 °C) and high relative humidity (Albornoz and Cantwell, 2016). However, frequently postharvest storage in the field, handling, transportation and spending phases take place at ambient temperature (Jones et al., 2006; Yuan et al., 2010).

* Corresponding author.
E-mail address: lorenzacosta@agro.unlp.edu.ar (L. Costa).

https://doi.org/10.1016/j.heliyon.2019.e02467
Received 21 June 2019; Received in revised form 5 August 2019; Accepted 9 September 2019

Thus, it is interesting to find economics and easy technologies to delay posthasvest senescence of leafy vegetables at room temperature as alternative to refrigeration.

During the last years, visible light treatments have been developed as a novel postharvest technology (Charles et al., 2018). Habitually during postharvest vegetables are storage in darkness, which induces and accelerates postharvest senescence. However, detached plant organs as isolated leaves and postharvest vegetables maintain responsiveness to light after harvest. If the light intensity is adequate, leaves can continue light-dependent biological processes like photosynthesis (Liebsch and Keech, 2016). In pre-harvest the contents of health-promoting compounds, as anthocyanin and other flavonoids, can be influenced by light intensity and/or light quality (Deng et al., 2017). During cultivation of kale, the profile of phenolic compounds can be influenced by light intensity (Neugart et al., 2012). Therefore, it is probably that light treatments can also affect the antioxidant content of kale leavesduring postharvest storage.

Some years ago, several works have demonstrated beneficial effects of light during storage; e.g. continues light exposition can retard tissue browning and maintained soluble sugars and ascorbic acid in fresh-cut romaine lettuces (Zhan et al., 2012, 2013). Continues low intensity light during postharvest delayed broccoli yellowing (Büchert et al., 2011) and improve nutritional qualities of spinach leaves (Lester et al., 2010). A treatment with low intensity continuous light during postharvest storage of Chinese kale was effective to prevent a decrease of antioxidants and increase the content of monosaccharides and starch in leaves of Chinese kale (Noichinda et al., 2007). Low intensity light pulses delayed postharvest senescence of spinach leaves (Gergoff Grozeff et al., 2013) and basil leaves (Costa et al., 2013). Recently, we have reported that treatments with daily pulses of (20 μmol m^{-2} s^{-1}) white or red light were effective to delay postharvest senescence of broccoli inflorescences stored at 20 °C (Favre et al., 2018). Commercial broccoli tissues are inflorescences while commercial kale tissues are leaves, therefore the effect of light treatment on each crop during postharvest storage probably could not be the same.

The purpose of the present study was to investigate if pulses of low intensity light treatments have effect on postharvest senescence of purple kale leaves, with special focus in pigments changes and antioxidant capacity during storage at room temperature. Light is the most important environmental factor influencing anthocyanin biosynthesis in plants and phytochromes are the photoreceptors involved in anthocyanin biosynthesis (Quail et al., 1995).

2. Materials and methods

2.1. Plant materials and experimental design

Purple kale (*Brassica oleracea* var. *sabellica*) was growing under field conditions in a farm near La Plata, Argentina (34°54′45.69″S, 57°55′50.39″W) from September to December 2017. Purple kale mature leaves were harvested early in the morning and immediately transported to the laboratory. Mature leaves were selected for uniformity of size, between 20-25 cm, and color. Three leaves were placed inside PVC (Polyvinyl chloride) food packaging perforated trays. Five trays were used for each treatment (n = 15): control (0 min of irradiation); white light (1 h of daily irradiation at 20–25 μmol m^{-2} s^{-1} provided by fluorescent lamps) and red light (1 h of daily irradiation at 20–25 μmol m^{-2} s^{-1} provided by fluorescent lamps with a LEE filters placed between lamps and leaves as described in Costa et al. (2013)). Irradiation treatments were applied on open trays. Light intensity and spectral qualities were controlled as described in Favre et al. (2018). Trays were stored at 20 °C in darkness. The weight of Kale leaves was taken daily and weight losses were calculated as percentage. Disks of kale leaves were taken at the beginning of the experiment (D0) and after 3 d of storage (D3) and were kept at -80 °C for biochemical determinations.

2.2. Photosynthesis–light response curves measurement

An infrared gas analyzer (IRGA, CIRAS II, PPSystems, UK) was used to measure net photosynthesis. The system allows for automated microclimate control in the leaf chamber. Before each measurement, leaves were adapted for 10 min to chamber conditions. CO_2 concentration was kept at 380 μmol mol^{-1}. To determine the response of net photosynthesis to light intensity, we varied irradiance from 0 to 800 mol m^{-2} s^{-1} PAR (400–700 nm), at 25 °C air temperature and 50% relative humidity. Three curves were analyzed.

2.3. Stomatal conductance of leaves

Stomatal conductance of Kale leaves was measured before and after light treatment. These measurements were made on four leaves. Stomatal conductance (gs) was measured with a steady state porometer (Decagon Devices, USA). Four leaves were used for each condition.

2.4. Chlorophyll and carotenoid content

Pigments content were determined spectrophotometrically according to Favre et al. (2018). Chlorophyll a, b, total and carotenoid contents were calculated by using Lichtenthaler's equations (Lichtenthaler, 1987). Results were expressed as μg of pigment per cm^{-2}. Four biological replicates per treatment were analyzed.

2.5. Anthocyanin content

Three cut leaf disc (1 cm diameter each) were homogenized with 1 ml 1% (v/v) HCl-methanol and kept at 4 °C for 90 min. The slurry was centrifuged at 3,000 x g for 15 min at 4 °C. The supernatant was used to determine anthocyanin content. Absorbance was measured in 200 μl of supernatant diluted with 800 μl of pH 1.0 solution (KCl 0.025 M adjust with HCl) and pH 4.5 buffer ($CH_3CO_2Na{\cdot}3H_2O$ 0.4 M adjust with HCl) at both 520 and 700 nm. Anthocyanin pigment concentration, expressed as cyanidin-3-glucoside equivalents, was calculated as Lee et al. (2005), using 26,900 molar extinction coefficient, in L $mol^{-1}cm^{-1}$, for cyanidin-3-glucoside. Results were expressed as μg of pigment per cm^{-2}. Four biological replicates per treatment were analyzed.

2.6. Soluble protein content

Soluble protein content was determined according Costa et al. (2013). Three cut leaf discs (1 cm diameter each) were used for each treatment and day. After centrifugation proteins in the supernatant were determined according to Bradford (1976) with bovine serum albumin as standard. Results were expressed as mg of proteins per cm^{-2}. Four biological replicates per treatment were analyzed.

2.7. Determination of total phenolic content

Total phenolic content was measured spectrophotometrically according to Costa et al. (2006). Five cut leaf discs (1 cm diameter each) were used for each treatment and day. Total phenolics were calculated by using a calibration curve with phenol as standard. Results were expressed as mg of phenol per $cm^{-2.}$ Four biological replicates per treatment were analyzed.

2.8. Antioxidant capacity

The free radical-scavenging capacity of kale leaves was tested according to Costa et al. (2005). Five cut leaf discs (1 cm diameter each) were used for each treatment and day. Leaf disk was homogenized with ethanol and centrifuged at 9000 x g for 10 min at 4 °C. The resulting supernatant was brought up to 100 ml with water. aliquots (5, 10, 20, 40, 80 and 120 μl) of the ethanolic extracts were added to test tubes

Table 1
Stomatal conductance of Kale leaves and light compensation point (i.e., the irradiance where photosynthesis balances respiration) for harvested kale leaves. Stomatal conductance was measured before and after white and red light treatment (WL and RL) after 3 d of treatment. Control samples (C) were leaves without light treatment. Each data represents the mean of three replicates. Different letters of each column indicate significant differences ($p < 0.05$) among treatments. Light compensation point was measured immediately after harvest in three different kale leaves.

	Stomatal conductance	
	Before treatment	After treatment
C D3	14,9 a	15,4 a
WL D3	16,3 a	21,5 b, c
RL D3	18,2 a, b	25,5 c

Light compensation point 39 ± 4 μmol m^{-2} s^{-1}.

containing 3.9 ml of 0.025 g l^{-1} 2,2-diphenyl-1-picrylhydrazyl (DPPH) in methanol, prepared fresh daily. The absorbance at 515 nm was measured at different times until the reaction reached a plateau. The percentage of remaining DPPH was then plotted against the extract volume to determine the amount of sample necessary to decrease the initial DPPH concentration by 50%, which was defined as EC50. The antioxidant power was expressed as EC50 $^{-1}$.

2.9. Sugar content

Soluble reducing sugar content was determined using Somogyi Nelson reaction (Hasperué et al., 2011) according Favre et al. (2018). Five cut leaf discs (1 cm each) were used for each treatment and day. After Somogyi Nelson reaction the absorbance was measured at 520 nm. Glucose was used as standard for calibration curve. Results were expressed as μg of sugar per cm^{-2}. Four biological replicates per treatment were performed.

2.10. Statistical analysis

The complete experiment was done two times and performed according to a factorial design. Fifteen leaves were used for each treatment (five trays with 3 leaves each). Data were analyzed by using analysis of variance (ANOVA) and means were compared by Tukey's Test at a significance level of 0.05.

3. Results and discussion

3.1. Light treatment during storage prevents loss of chlorophylls and proteins in purple kale leaves

Leafy vegetables have a high surface/volume ratio and therefore exposed to a high dehydration (Kader, 2002). The turgor of the leaves is an important factor of quality in kale, and weight loss is an excellent way of measuring the degree of dehydration and loss of turgor during postharvest storage. In a preliminary trial, an irradiation with 2 h of low intensity white light similar to that described for broccoli treatment (Favre et al., 2018) was performed. However, we detected an excessive weight loss, possibly because kale leaves result more sensible to dehydration than broccoli inflorescences. Daily irradiation with 1 h of low intensity light showed a significant impact on fresh weight loss of kale leaves thought visual appearance was adequate. Control samples reduced

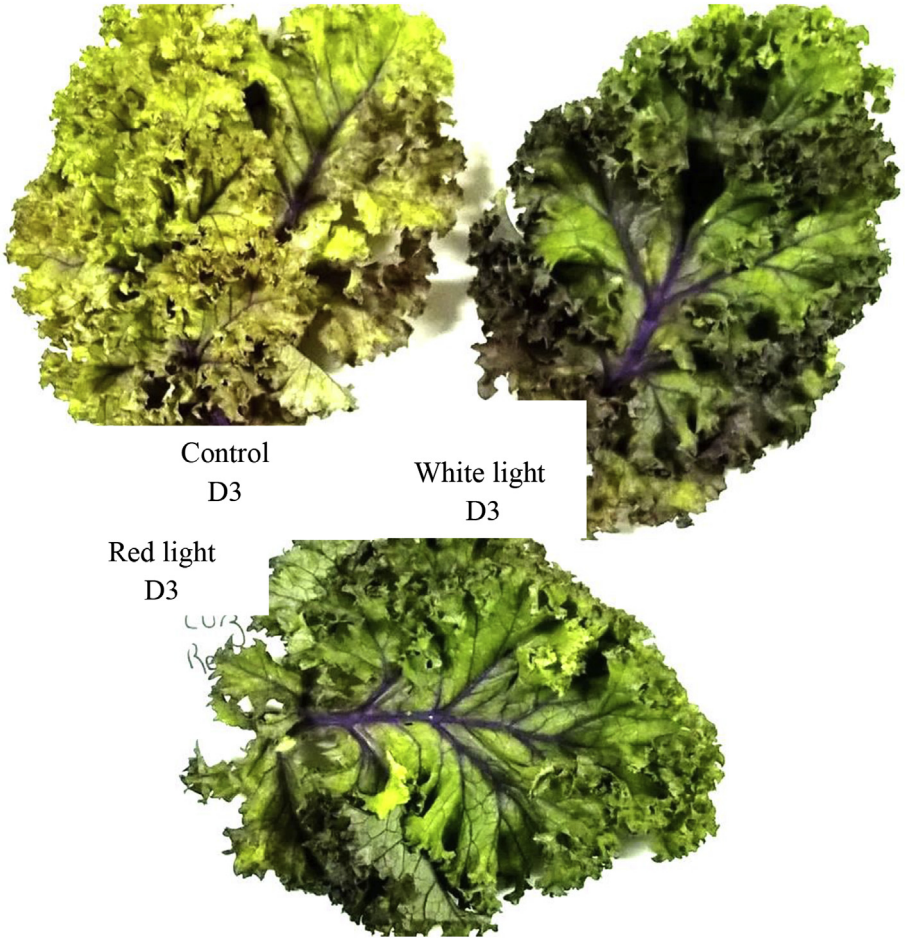

Fig. 1. Photos of kale leaves after 3 days of storage at room temperature.

their weight in around 2 % while in both white and red light treatments weight loss was around 6 % after 3 d at 20 °C. Stomatal conductance was measured before and after light treatment (Table 1). As expected, after light treatment stomatal conductance increased in kale treated leaves while there were no changes in control samples (Table 1). It was showed that white and blue light are the responsible for regulation of stomata aperture (Eckert and Kaldenhoff, 2000). Transpiration can occur through the stomata pores of leaves; however the overall appearance of irradiated kale with white or red light was better than control at the end of the experiment in spite of weight loss (Fig. 1). Our results are similar to those described by Noichinda et al. (2007) for Chinese kale.

The main objective of this study was to evaluate the possibility of using pulses of low intensity light during storage of purple kale to delay senescence induced by harvesting. Storage of excised leaves in darkness causes chlorophyll and protein breakdown, typical indicators of progression of senescence in green tissues (Noodén et al., 1997). A significant decrease of total chlorophyll was observed in kale leaves after 3 d of storage at 20 °C (Fig. 2A). Approximately 62 % of the initial chlorophyll content was loss in control leaves (stored in darkness) while white or red light treated leaves loss only 20 % of initial chlorophyll (Fig. 2A). Thus, daily pulses of white or red light can delay chlorophyll degradation during postharvest senescence of kale at 20 °C. Total chlorophyll degradation was delayed by light treatments regardless of quality light (Fig. 2A). Immediately after harvest, control samples had similar levels of both types of chlorophylls a (Chla) and b (Chlb) while after three days Chla level was twice Chlb level (Fig. 2B and C). Chla declined only in control samples (Fig. 2B) while Chlb level declined in all treatments although in light treatments the decrease was lower than the control (Fig. 2C). These results could be due to the fact that the first step of Chlb degradation is conversion to Chla (Hörtensteiner, 2006) and low intensity light treatment delayed strongly Chla degradation and thus Chlb degradation was slowed.

As mentioned above, another characteristic symptom of senescence in leaves is that chloroplast proteins are extensively degraded (Noodén et al., 1997; Mae, 2004). Soluble protein content of non-treated kale leaves diminished during storage, showing an important decrease of about 75 %, after 3 d at 20 °C (Fig. 3). In contrast, irradiated leaves with red light retained their protein content respect to initial value, whereas in

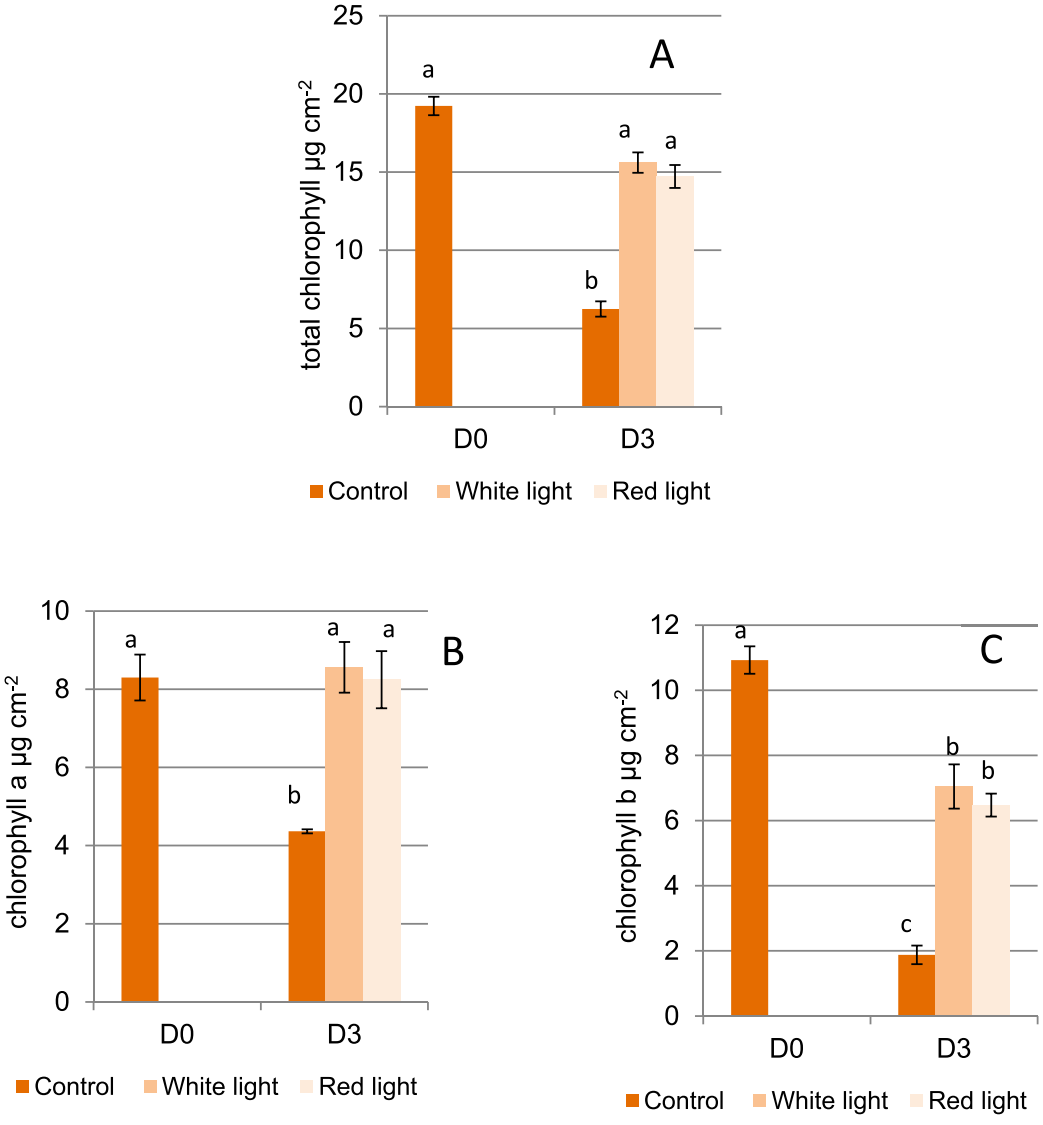

Fig. 2. Changes in total chlorophyll (A), chlorophyll a (B) and chlorophyll b (C) content in purple kale leaves after 0 (D0) and 3 d (D3) at 20 °C. Leaves received low intensity light pulses for 1 h every day. Four independent extracts were made for each sampling date and treatment. Chlorophyll content was expressed as µg per area unit. Each data point represents the mean of four replicates. Different letters indicate statistical differences ($p < 0.05$).

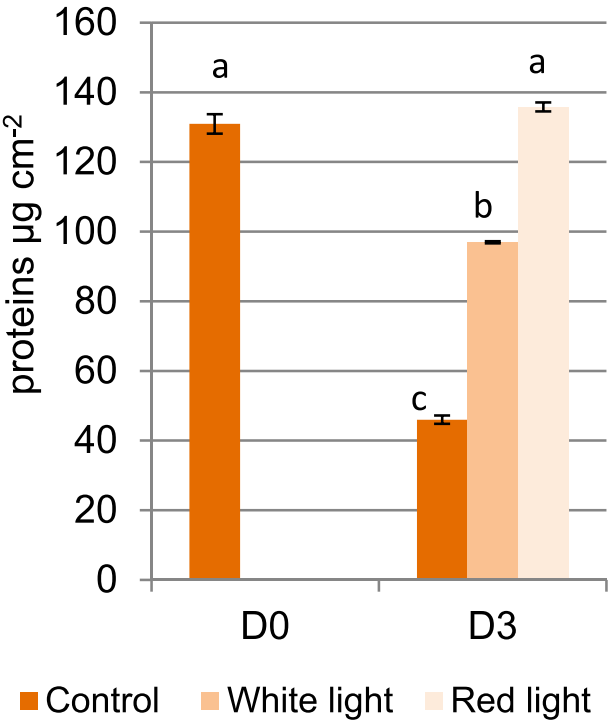

Fig. 3. Changes in protein content in purple kale leaves after 0 (D0) and 3 d (D3) at 20 °C. Leaves received low intensity light pulses for 1 h every day. Four independent extracts were made for each sampling date and treatment. Protein content was expressed as µg per area unit. Each data point represents the mean of four replicates. Different letters indicate statistical differences ($p < 0.05$).

white light treatment proteins decreased slightly after 3 d, showing a decrease of about 36 % and maintaining higher levels than that of the corresponding controls. These results suggest that red light pulses were more effective than white light to delay postharvest senescence of kale leaves, in terms of protein retention. Our result are consistent with the idea that plants over-expressing phytochromes have a delayed leaf senescence (Rousseaux et al., 1997) whereas phytochromes mutant plants increased leaf yellowing in response to shade (Brouwer et al., 2012).

3.2. Light treatment preserved postharvest qualities of purple kale leaves

Kale (*Brassica oleracea* var. *sabellica*) is an excellent source of dietary carotenoids among green leafy vegetables due to its high concentrations of lutein and zeaxanthin (Walsh et al., 2015). After 3 d of storage at 20 °C, carotenoids level of kale leaves remains constant regardless of the treatment (Fig. 4A). These results are similar to those showed in a previous study in which it was determined that the level of carotenoids in mature leaves of kale did not change during postharvest storage at room temperature (Albornoz and Cantwell, 2016). With regard to the effect of light treatment, our results are different from those described by Hasperué et al. (2016) in broccoli heads. They observed an increase of carotenoid after 3 d at 22 °C in samples of broccoli irradiated with similar low intensity white light. However, they used continues irradiation and it is possible that some type of acclimatization of florets could occur rendering a positive effect on carotenoids accumulation (Woitsch and Romer, 2003; Briggs and Olney, 2007). Nevertheless, another difference could be the type of tissue; the head of broccoli is an inflorescence and the accumulation of carotenoids detected by Hasperué et al. (2016) could be due to the development of the petals.

While the carotenoids content was similar in all samples along the experiments, anthocyanin degradation was different according to the irradiation treatment utilized. After 3 d at 20 °C control leaves retained 43 % of anthocyanin, white light treated samples retained 67 % and red light treated leaves retained 71 %, although there was no significant difference between light treatments (Fig. 4B). Anthocyanin pigments are important to kale quality because of their contribution to color and appearance. Thus the high level of anthocyanin remained in treated samples along storage result in better appearance of leaves (Fig. 1). Additionally, nutritional quality of irradiated leaves was also improved due to their higher level of carotenoids and anthocyanin in relation to controls.

Finally, due to the resulting color of purple kale leaves is the consequence of combination of green (chlorophyll) purple (anthocyanin) and yellow (carotenoids), the ratio between pigment content after 3 d at 20 °C was also calculated (Table 2). During storage the ratio chlorophyll/carotenoids, chlorophyll/anthocyanin and anthocyanin/carotenoids decreased approximately 50%, 30% and 60% respectively in control samples. During senescence of purple kale, the carotenoids become the main pigments, being this probably the main cause of the yellowish color of this vegetable in its senescent state. Low intensity light pulses delayed these changes in pigments balance regardless of light quality. It is important to note that color is one of the most relevant traits for

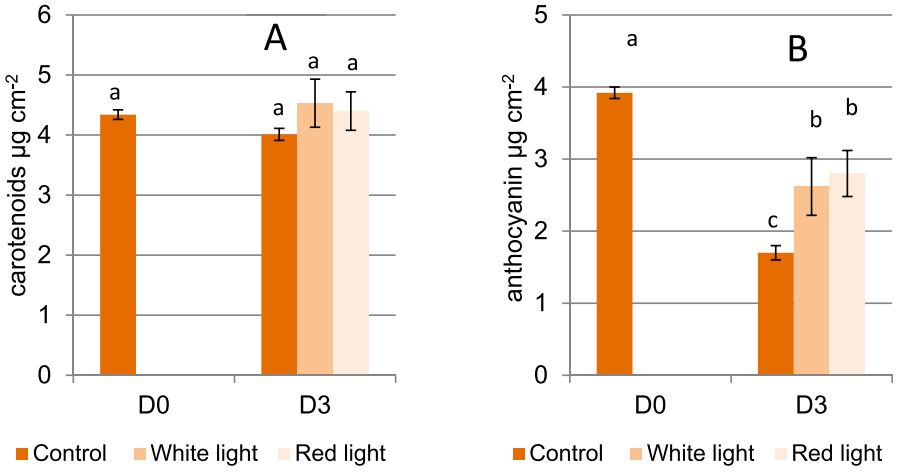

Fig. 4. Changes in the levels of carotenoids (A) and anthocyanin (B) in purple kale leaves given low intensity white or red light pulses (20 µmol m^{-2} s^{-1}) for 1 h every day and then stored in darkness at 20 °C for 3 d (D3). The parameters are expressed on the basis of leaf area. Four independent extracts were made for each sampling date and treatment. Bars indicate the standard deviation. Different letters mean statistical differences ($p < 0.05$).

Table 2
Pigments ratio in purple kale leaves after 0 (D0) and 3 d (D3) at 20 °C. Each data is the result of dividing pigment contents in the same biological replica. Each data represents the mean of four replicates. Different letters of each column indicate significant differences ($p < 0.05$) between treatments.

	Chlorophyll/ carotenoids	Chlorophyll/ anthocyanin	Anthocyanin/ carotenoids
D0	5.4 ± 0.7 a	6.0 ± 0,7 b	0.9 ± 0.08 a
C D3	2.2 ± 1.2c	5.2 ± 0.7 c	0.4 ± 0.05 c
WL D3	4.1 ± 0.5 b	7.1 ± 0,5 a	0.6 ± 0.08 b
RL D3	4.4 ± 0.4 b	6.9 ± 0.6 a	0.6 ± 0.1 b

consumers, playing a crucial role in preference and acceptability in purple kale and may also be considered as an indicator for estimating the shelf-life of vegetables (Ali et al., 2009). The maintenance of pigment balance in treated leaves rendered a better color of purple kale and; also allowed preserving a higher content of pigments with possible health benefits.

Phenolic compounds, one of the main antioxidants in *Brassica* spp. vegetables, protect cells against oxidative damage by directly scavenging free radicals, and therefore bring benefits to human health (Podsedek, 2007). In control samples, no changes were observed in the level of phenolics compounds after 3 d (Fig. 5A). Unexpectedly, light treatments caused a slight decrement in the level of total phenolic at the end of the experiment. Enzymatic browning in green leaves occurs when the metabolism of phenylpropanoids is activated and the accumulation of phenolic compounds may increase susceptibility to browning (Saltviet and Choi, 2007). Simões et al. (2015) detected increasing browning in kale leaves during storage and attributed this change to phenylpropanoids accumulation. Since phenolic compounds accumulation affects visual color of purple kale, light treatments have a positive effect on this detrimental change. Concomitant with these findings, both an increment and a decrement in the content of phenolics were reported during postharvest senescence of different brassicas (Costa et al., 2006; Sun et al., 2012; Favre et al., 2018). The heterogeneity of these results could be explained by the broad variety in the biosynthesis metabolism, composition and concentration of phenolic compounds among leafy vegetables. Moreover genetic and environmental factors (light and temperature), growing conditions, harvest practices and postharvest handling conditions may also affect the content of phenolic compounds (Rouphael et al., 2012; Neugart et al., 2012, 2013).

The level of antioxidants decreased after 3 d at 20 °C in kale leaves, as indicated by the decrease in $EC50^{-1}$ values (Fig. 5B). Control samples decreased their antioxidant capacity reaching a decrement of almost 50%. Light treatments had a positive effect in antioxidant capacity since treated samples showed levels of antioxidant compounds significantly higher than controls after 3 d (Fig. 5B).

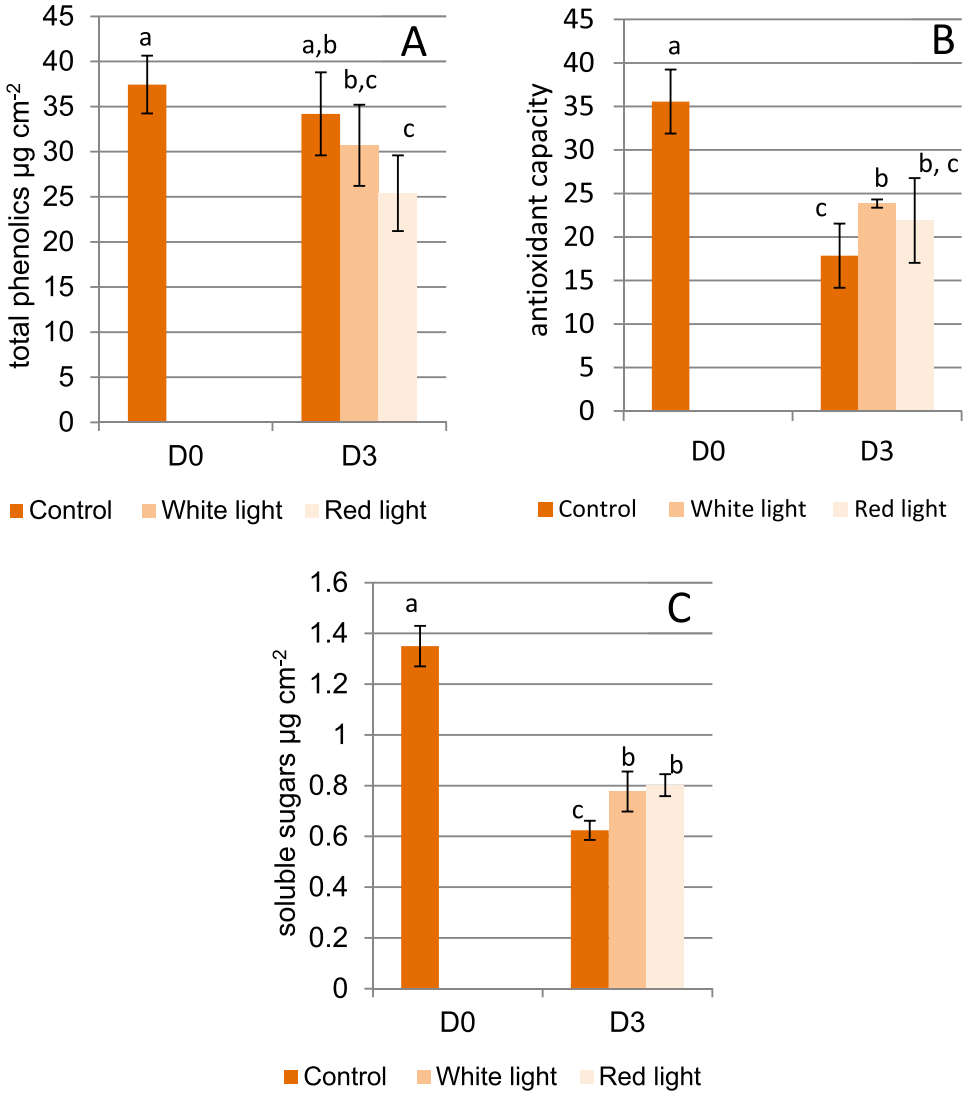

Fig. 5. Changes in the levels of total phenolics (A), antioxidant capacity (B) and soluble sugars (C) in purple kale leaves treated with low intensity white or red light pulses (20 µmol m^{-2} s^{-1}) for 1 h every day and stored in darkness at 20 °C for 3 d (D3). The parameters total phenolics and sugar are expressed on the basis of leaf area (A, C). The antioxidant capacity (B) was expressed as $EC50^{-1}$ (the amount of sample necessary to decrease the initial DPPH concentration by 50% was defined as EC50). Four independent extracts were made for each sampling date and treatment. Bars indicate the standard deviation. Different letters mean statistical differences ($p < 0.05$).

Different pattern was detected for the content phenolic compounds and antioxidant capacity (Fig. 5A and B) indicating that there was no correlation between these compounds in kale. These results suggest that it is possible that carotenoids, anthocyanin and ascorbic acid can be the major antioxidant compounds in kale. Light treatment retained anthocyanin and carotenoids (Fig. 4) and maybe ascorbic acid too as in other Brassicaceae (Bell et al., 2017). Phenolic compounds are a large class of plant secondary metabolites, showing a diversity of structures, from rather simple structures, e.g. phenolic acids, through polyphenols such as flavonoids, that comprise several groups, to polymeric compounds based on these different classes (Cheynier, 2012).

Photosynthesis vs. light response curves determined a light compensation point (i.e., the irradiance where photosynthesis balances respiration) for harvested kale leaves of about 39 μmol m^{-2} s^{-1} (Table 1). The light treatment used here was between 20 and 25 mol m^{-2} s^{-1}, i.e., below the light compensation point, therefore the possible positive impact of light pulses on carbon balance may have been probably negligible. Additionally, soluble sugar content decreased during storage in both control and treated kale leaves, but the decline was greatest in leaves stored in the dark. In non-treated leaves soluble sugars decreased by about 55% after 3 d in darkness at 20 °C, whereas sugar content was 15 % higher in treated leaves up to the end of the storage period, regardless of light quality utilized (Fig. 5C). Phytochromes are involved in regulation of ethylene biosynthesis and signaling which could impact on delaying respiration rate (Mancinelli et al., 1991); therefore light treatment delayed sugar consumption by a lower respiration rate during storage. Additionally, this higher hexose level could work as regulator to delay senescence progress. Hasperué et al. (2011) and Irving and Joyce (1995) have demonstrated that hexoses can delay senescence of broccoli, and our result could agree with this affirmation.

4. Conclusion

Regardless of the quality of light used, white or red, the treatment was effective to improve purple kale preservation at room temperature. Irradiated samples during 1 h daily with low intensity light showed higher chlorophyll, protein, antioxidant capacity and soluble sugar content than non-irradiated ones. Both qualities light, white or red had similar effect on chlorophyll, carotenoids and anthocyanins retention during postharvest senescence of kale leaves. Although the content of phenols was not increased in the irradiated kale as in the control ones, light treatments had a positive effect in antioxidant capacity of kale leaves. Therefore white and red light treatments have the potential utility of improving both the appearance and nutritional quality of purple kale during postharvest storage at room temperature.

Declarations

Author contribution statement

Alejandra Bárcena: Performed the experiments; Analyzed and interpreted the data.

Gustavo Martinez: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Lorenza Cost: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by funds from CONICET and UNLP, Argentina (PIO 2018 CONICET-UNLP).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

Bárcena holds a fellowship from CONICET; Martínez is a researcher from CONICET and Costa is a researcher from CONICET and FCAyF-UNLP. We thank our technicians from CONICET, Mauro Bartolozzi and Santiago Martínez for helping with the adequate light treatment facilities. We thank Corina Graciano for her help with the IRGA measurements and Joaquin Hasperué for his help with antioxidant measurements.

References

Albornoz, K., Cantwell, M., 2016 October. Fresh-cut kale quality and shelf-life in relation to leaf maturity and storage temperature (Conference Paper). Acta Hortic. (Wagening.) 1141, 109–116.

Ali, M.B., Khandaker, L., Oba, S., 2009. Comparative study on functional components, antioxidant activity and colour parameters of selected colored leafy vegetables as affected by photoperiods. J. Food Agric. Environ. 7, 392–398.

Bell, L., Yahya, H.N., Oloyede, O.O., Methven, L., Wagstaff, C., 2017. Changes in rocket salad phytochemicals within the commercial supply chain: glucosinolates, isothiocyanates , amino acids and bacterial load increase significantly after processing. Food Chem. 221, 521–534.

Björkman, M., Klingen, I., Birch, A.N.E., Bones, A.M., Bruce, T.J.A., Johansen, T.J., Meadow, R., 2011. Phytochemicals of Brassicaceae in plant protection and human health Influences of climate, environment and agronomic practice. Phytochemistry 72 (7), 538–556.

Bradford, M.M., 1976. A rapid and sensitive method for quantization of microgram quantities of protein utilizing the principle of protein–dye-binding. Anal. Biochem. 72, 248–254.

Briggs, W., Olney, M., 2007. Photoreceptors in plant photomorphogenesis to date. Five phytochromes, two Cryptochromes, one phototropin, and one superchrom. Plant Physiol. 125, 85–88.

Brouwer, B., Ziolkowska, A., Bagard, M., Keech, O., Gardeström, P., 2012. The impact of light intensity on shade-induced leaf senescence. Plant Cell Environ. 35, 1084–1098.

Büchert, A.M., Gómez Lobato, M.E., Villarreal, N.M., Civello, P.M., Martínez, G.A., 2011. Effect of visible light treatments on postharvest senescence of broccoli (Brassica oleracea L.). J. Sci. Food Agric. 91, 355–361.

Charles, F., Nilpraprucka, P., Rouxa, D., Sallanona, H., 2018. Visible light as a new tool to maintain fresh-cut lettuce post-harvest quality. Postharvest Biol. Technol. 135, 51–56.

Cheynier, V., 2012. Phenolic compounds: from plants to foods. Phytochem. Rev. 11, 153.

Costa, L., Civello, M., Chaves, A., Martínez, G., 2005. Effect of hot air treatments on senescence and quality parameters of harvested broccoli (Brassica oleracea L var Italica) heads. J. Sci. Food Agric. 85, 1154–1160.

Costa, L., Vicente, A., Civello, M., Martínez, G., Chaves, A., 2006. UV-C treatments delays postharvest senescente in broccoli florets. Postharvest Biol. Technol. 39, 115–222.

Costa, L., Millan Montano, Y., Carrión, C., Rolny, N., Guiamet, J.J., 2013. Application of low intensity light pulses to delay postharvest senescence of Ocimum basilicum leaves. Postharvest Biol. Technol. 86, 181–191.

Deng, M., Qian, H., Chen, L., Sun, B., Chang, J., Miao, H., Cai, C., Wang, O., 2017. Influence of pre-harvest red light irradiation on main phytochemicals and antioxidant activity of Chinese kale sprouts. Food Chem. 222, 1–5.

Eckert, M., Kaldenhoff, R., 2000. Light – induced stomatal movement of selected Arabidopsis thaliana mutants. J. Exp. Bot. 51 (349), 1435–1442.

Favre, N., Bárcena, A., Vera Bahima, J., Martínez, G., Costa, L., 2018. Pulses of low intensity light as promising technology to delay postharvest senescence of broccoli. Postharvest Biol. Technol. 142, 107–114.

Gergoff Grozeff, G.E., Chaves, A.R., Bartoli, C.G., 2013. Low irradiance pulses improve postharvest quality of spinach leaves (Spinacia oleraceae L. cv Bison). Postharvest Biol. Technol. 77, 35–42.

Hasperué, J.H., Chaves, A.R., Martínez, G.A., 2011. End of day harvest delays postharvest senescence of broccoli florets. Postharvest Biol. Technol. 59, 64–70.

Hasperué, J.H., Guardianelli, L., Rodoni, L.M., Chaves, A.R., Martínez, G.A., 2016. Continuous white-blue LED light exposition delays postharvest senescence of broccoli. LWT –Food Sci. Technol. 65, 495–502.

Hörtensteiner, S., 2006. Chlorophyll degradation during senescence. Annu. Rev. Plant Biol. 57, 55–77.

Irving, D.D., Joyce, D.C., 1995. Sucrose supply can increase longevity of broccoli (Brassica oleracea) branchlets kept at 22 °C. Plant Growth Regul. 17, 251–256.

Jones, R.B., Faragher, D.J., Winkler, S., 2006. A review of the influence of postharvest treatments on quality and glucosinolate content in broccoli (Brassica oleracea var. italica) heads. Postharvest Biol. Technol. 41 (1), 1–8.

Kader, A.A., 2002. Postharvest Biology and technology: an overview. Postharvest Technology of Horticultural Crops. University of California, Agriculture and Natural Resources, third ed., p. 520 Publication 3529.

Lee, J., Durst, R.W., Wrolstad, E., 2005. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study. J. AOAC Int. 88 (5), 1269–1278.

Lester, G.E., Makus, D.J., Hodges, D.M., 2010. Relationship between fresh-packaged spinach leaves exposed to continuous light or dark and bioactive contents: effects of cultivar, leaf size, and storage duration. J. Agric. Food Chem. 58, 2980–2987.
Lichtenthaler, H.K., 1987. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. Methods Enzymol. 148, 350–382.
Liebsch, Daniela, Keech, Oliver, 2016. Dark-induced leaf senescence: new insights into a complex light-dependent regulatory pathway. New Phytol. 212, 563–570.
Mae, T., 2004. Leaf senescence and nitrogen metabolism. In: Noodén, L.D. (Ed.), Plant Cell Death Processes. Academic Press, San Diego, CA, USA, pp. 157–168.
Mancinelli, A.L., Rossi, F., Moroni, A., 1991. Cryptochrome, phytochrome, and anthocyanin production. Plant Physiol. 96, 1079–1085.
Neugart, S., Klaring, H.-P., Zietz, M., Schreiner, M., Rohn, S., Kroh, L.W., Krumbein, A., 2012. The effect of temperature and radiation on flavonol aglycones and flavonol glycosides of kale (Brassica oleracea var. sabellica). Food Chem. 133, 1456–1465.
Neugart, S., Fiol, M., Schreiner, M., Rohn, S., Zrenner, R., Kroh, L.W., Krumbein, A., 2013. Low and moderate photosynthetically active radiation affects the flavonol glycosides and hydroxycinnamic acid derivatives in kale (Brassica oleracea var. sabellica) dependent on two low temperatures. Plant Physiol. Biochem. 72, 161–168.
Neill, S.O., Gould, K.S., 2003. Anthocyanins in leaves: light attenuators or antioxidants? Funct. Plant Biol. 865–873.
Noichinda, S., Bodhipadma, K., Mahamontri, C., Narongruk, T., Ketsa, S., 2007. Light during storage prevents loss of ascorbic acid, and increases glucose and fructose levels in Chinese kale (Brassica oleracea var. alboglabra). Postharvest Biol. Technol. 44, 312–315.
Noodén, L.D., Guiamet, J.J., John, I., 1997. Senescence mechanisms. Physiol. Plant. 101, 746–753.
Podsedek, A., 2007. Natural antioxidants and antioxidant capacity of Brassica vegetables: a review. LWT-Food Sci. Technol. 40 (1), 1–11.
Pojer, E., Mattivi, F., Johnson, D., Stockley, C.S., 2013. The case for anthocyanin consumption to promote human health: a review. Compr. Rev. Food Sci. Food Saf. 12, 483–508.
Quail, P.H., Boylan, M.T., Parks, B.M., Short, T.W., Xu, Y., Wagner, D., 1995. Phytochromes: photosensory perception and signal transduction. Science 268 (5211), 675–680.
Rouphael, Y., Cardarelli, M., Bassal, A., Leonardi, C., Giuffrida, F., Colla, G., 2012. Vegetable quality as affected by genetic, agronomic and environmental factors. J. Food Agric. Environ. 10, 680–688.
Rousseaux, M.C., Ballare, C.L., Jordan, E.T., Vierstra, R.D., 1997. Directed over-expression of PHYA locally suppresses stem elongation and leaf senescence responses to far-red radiation. Plant Cell Environ. 20, 1551–1558.
Saltveit, M.E., Choi, Y., 2007. Aromatic- and dicarboxylates inhibit wound-induced phenolic accumulation in excised lettuce (Lactuca sativa L.) leaf tissue. Postharvest Biol. Technol. 46 (3), 222–229.
Simões, A., Moreira, S., Mosquim, P., Ferreira Soares, M., Puschmann, R., 2015. The effects of storage temperature on the quality and phenolic metabolism of whole and minimally processed kale leaves. Acta Scientiarum. Agronomy. Maringá 37 (1), 101–107.
Sun, B., Yan, H., Liu, N., Wei, J., Wang, Q., 2012. Effect of 1-MCP treatment on postharvest quality characters, antioxidants and glucosinolates of Chinese kale. Food Chem. 131 (2), 519–526.
Wang, C., 1998. Heat treatment affects postharvest quality of kale and collard but not of brussels sprouts. Hortscience 33 (5), 881–883.
Walsh, R., Bartlett, H., Eperjesi, F., 2015. Variation in carotenoid content of kale and other vegetables: a review of pre- and post-harvest effects. J. Agric. Food Chem. 63, 9677–9682.
Woitsch, S., Romer, S., 2003. Expression of xanthophyll biosynthetic genes during light-dependent chloroplast differentiation. Plant Physiol. 132, 1508–1517.
Yuan, G.F., Sun, B., Yuan, J., Wang, Q.M., 2010. Effect of 1-methylcyclopropene on shelf life, visual quality, antioxidant enzymes and health-promoting compounds in broccoli florets. Food Chem. 118, 774–781.
Zhan, L., Li, Y., Hu, J., Pang, L., Fan, H., 2012. Browning inhibition and quality preservation of fresh-cut romaine lettuce exposed to high intensity light. Innov. Food Sci. Emerg. Technol. 14, 70–76.
Zhan, L., Hu, J., Ai, Z., Pang, L., Li, Y., Zhu, M., 2013. Light exposure during storage preserving soluble sugar and l-ascorbic acid content of minimally processed romaine lettuce (Lactuca sativa L. var longifolia). Food Chem. 136, 273–278.